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NOTE ON BAKED CLAYS AND NATURAL SLAGS IN EASTERN WYOMING

E. S. BASTIN
Chicago

A striking feature of the country just to the east of the Big Horn Mountains, and one which adds greatly to its picturesqueness, is the widespread development of red beds and slaglike materials in consequence of the burning-out of lignite beds in the Laramie division of the Cretaceous. The baking and accompanying reddening of the sandstones and clays have in some districts been so extensive that the landscape somewhat resembles that of the typical "Red Beds" of Jura-Trias age.

Explorers and geologists who have visited this region, from the times of Lewis and Clarke down to the present day, have noted the occurrence and characteristics of these beds, and have in most cases properly interpreted their origin. Mr. J. A. Allen, who accompanied the Northern Pacific Railroad Expedition, has given us an excellent account[1] of these beds, and has summarized the previous literature. It is the intention here merely to add a few notes on the field occurrences and something as to the microscopic characters.

At the suggestion of Professor R. D. Salisbury, Mr. A. E. Taylor and the writer spent a few days in the study of these beds during the summer of 1903. These studies were confined to the district between Gillette and Buffalo, Wyo., but beds of a similar nature give color to the landscape and exert a notable influence upon the topography over a much more extensive region. Their occurrence has been reported over practically the whole northeastern quarter of the state of Wyoming, and over an area of about equal size in southeastern Montana and adjacent parts of the Dakotas—a total extent of at least 100,000 miles. This vast region is characterized by horizontal or gently inclined strata, made up largely of clays and fine sands, with occasional seams of lignitic coal, the latter usually only a foot or two in thickness, but occasionally reaching a thickness of eight or ten feet. The beds have been sculptured by erosion into typical "Bad Lands" forms, giving the coal beds a large area of outcrop, and thus greatly facilitating their combustion.

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[1] *Proceedings of the Boston Society of Natural History*, Vol. XVI (1874), pp. 246 ff.

The ignition of the coal has in certain cases taken place through human agencies, as in the case of a bed now burning (summer of 1903) six miles west of Gillette, Wyo., which was set on fire in 1902 by laborers at work on the railroad; in most cases, however, we must attribute their ignition to spontaneous combustion, or, at any rate, to agencies other than human. At the locality above referred to, the coal outcrops along the sides of a deep gulch, and its burning is accompanied by the emission of much heat and of considerable volumes of sulphurous gases.

The unburned strata are typically of a gray or buff color, but upon the burning-out of an underlying coal seam they assume most gaudy hues of bright yellow, pink, or deep brick-red; the stratum beneath the coal is usually but little affected. Frequently a red layer may be traced from butte to butte, in each case underlain by the ash of the burned-out coal seam. With the change in color go incipient fusion and an increase in the coherence and resistance of the strata. This increased resistance has had a marked influence upon the topography, and it is common to find buttes capped with a layer of this baked material which has served to retard the progress of normal erosion.

Rocks resulting from the baking and fusion above described have been referred to by German geologists under the names *Porzellanit* and *Porzellanjaspis*[1] and have been observed by them in a number of the European coal fields. Similar materials have been observed by the writer in the Coal Measures near La Salle, Ill. The principal varieties of altered material observed in the Wyoming region are described below.

1. By far the largest part of the metamorphosed beds consists of buff, brick-red, or indian-red argillaceous material. Much of this is fissile along bedding-planes, and incloses lamellibranch shells and shows impressions of leaves in great perfection; other portions are more massive and show a somewhat conchoidal fracture; still

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[1] Zirkel, *Lehrbuch der Petrographie,* Vol. III, p. 775.

other portions, especially near the slaglike masses (No. 3, below), are extensively and very irregularly fractured. The metamorphism of these rocks finds a parallel in the artificial process of the burning of bricks, and consists simply in an oxidation of the iron from the ferrous to the ferric state, and in incipient fusion which greatly increases the coherence.

2. The coal itself leaves behind a typical ash upon burning; most of this is loose and incoherent, but some parts are clinker-like.

3. Slaglike masses make up only a small proportion of the beds, but are striking because of their close resemblance to lavas. They form very irregular, dark brown or mottled, vesicular masses, and usually inclose numerous fragments of shale and sandstone. Occasionally the slag occurs as an uneven layer just above the burned-out coal bed, but in most of the localities visited by the writer it formed isolated masses which in many instances seemed to be almost surrounded by the baked clays described above. Allen[1] also describes "chimney-like" forms a few feet in diameter capping buttes because of their superior resistance. The forms of the slaglike masses, and the sharp transition to beds which have been but slightly metamorphosed, suggest that they represent channels of easy exit for the hot gases and vapors, along which the metamorphism was much more considerable than in any other portion, except immediately above the coal bed, where slags are also occasionally developed. The ropy surfaces exhibited by some of the slags show how fluid much of the material must have been.

4. The inclosing argillite near the slaglike masses has in most cases been much brecciated, and one of the characteristic types of rock is formed by the penetration of the crevices of such breccia by the slag. The process usually results in the induration of the breccia fragments to hard, flintlike masses, red, buff, or gray in color.

A microscopic examination of one of these slag veins in red argillite showed a central, relatively coarsely holocrystalline mass about one-tenth of an inch across. This was bordered on each side by a zone about one-fiftieth of an inch wide, fine-grained, prevailingly gray in color, and apparently representing the contact effect of the slag on the argillite. Outside this narrow zone the argillite shows a reddish tint. In passing from the reddish argillite towards the center of the vein, the contact zone shows a gradual decrease in the normal shale constituents and a development, in increasing amount and coarseness, of purplish-blue, pleochroic cordierite. Next the coarser part of the vein this mineral is present to the exclusion of all others. In this contact zone the red iron oxide of the argillite has been wholly reduced to magnetite. The central portion of the vein is a somewhat vesicular, holocrystalline mass, consisting of abundant magnetite in irregular masses, some hematite, usually lining the vesicles and following fractures, and abundant cordierite, feldspar, and pyroxene. The cordierite occurs in good-sized grains, some of which have a very irregular outline, while others show very definite crystalline forms, occurring in short prisms whose very perfect hexagonal cross-sections are the result of characteristic repeated twinning, as is shown by the optical properties. The feldspar occurs in narrow lath-shaped crystals with irregular terminations, and often with irregular lateral boundaries. No crystals were found which showed more than two twinning lamellæ. The index of refraction is slightly above that of the balsam, and about equal to that of cordierite. This character, and the low extinction angles (less than 3°), fix its composition as oligoclase. Pyroxene occurs, sometimes in grains, but mainly in long, prismatic crystals, whose length ranges from ten to almost fifty times their width. The pleochroism is moderately strong; the colors for rays vibrating parallel to the prism length range from deep green to greenish-yellow, with occasional portions of the prism which are reddish-brown; for rays vibrating perpendicular to the prism, the color is usually greenish-yellow. Cross-sections show typical pyroxene cleavage, and the extinction angles range up to 32°.

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[1] *Ibid.*, p. 250.

5. A small proportion of the beds are fine-grained, porous sandstone which, upon baking, assumes the brilliant colors observed in the clayey members. Microscopically the slag is seen to penetrate this porous rock so thoroughly that it is impossible to draw a sharp line between the slag and the original sandstone. The sandstone, consisting of small angular quartz grains, fine argillaceous material, and hematite in scattered grains and as a fine coating on the other minerals, passes into a glassy mass inclosing scattered quartzes and

abundant minute crystals of hematite, the latter frequently grouped in aggregates; this in turn passes into a vesicular, dark gray mass in which distinct quartz fragments are absent, the iron largely in the form of magnetite, and cordierite very extensively developed; some feldspar may perhaps be present, but could not be identified.

The complete crystallization of a vein of slag one-tenth of an inch across, and the perfect development of many of the crystals, are probably to be explained by high temperature of the rock walls when the slag flowed in, and a consequent slow cooling. In general, the physical conditions under which the metamorphism took place are similar to those in the slag furnace, and the resulting products are slaglike in appearance. The materials involved are, however, somewhat different from those of most slags. They are typical pelites, and it is not surprising that one of the minerals most abundantly developed, cordierite, should be a mineral rarely found in artificial slags, but one of the commonest minerals developed in the contact metamorphism of pelitic sediments.